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PROBABILITY OF HYDROGEN IONIZATION BY ELECTRON IMPACT

by

E. V. Kononovich

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DRAFT TRANSLATION

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ABSTRACT

The probability of hydrogen ionization from the ground state by electron impact has been computed on the basis of experimental data [5]. These results are compared with those of other authors.

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COVER-TO-COVER TRANSLATION

Hydrogen ionization in the solar chromosphere and corona takes place mainly as a consequence of neutral atom collisions with electrons. The probability of this process valid from the level n is

$$Q_{ni} = n_e \sqrt{\frac{8kT_e}{\pi m_e}} \int\limits_{\chi_n/kT_e}^{\infty} q(x)\, x e^{-x}\, dx, \qquad (1)$$

and was computed by a series of authors [1 — 4]. The discrepancies between the results obtained are explained by the variation of approximate formulae utilized for the differential effective

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* Veroyatnost' ionizatsii vodoroda elektronnym udarom.

cross-section q (x). At the same time for ionization from a ground level the most reliable are the experimental values of q (E) obtained by Fite and Brackmann [5], who measured the effective cross sections especially for cases of low energies. Their results, together with the various approximations applied, are plotted in Fig. 1.

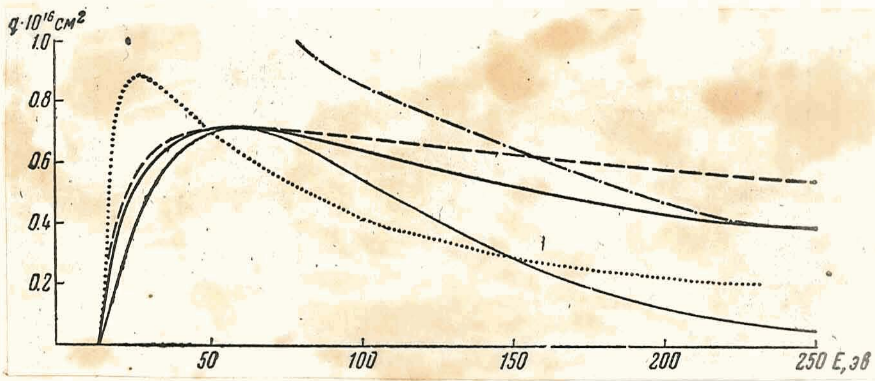

Fig. 1. Effective ionization cross section of hydrogen from the ground state : 1 — heavy solid line — observations [5]; 2— dash correspond to formula (2); 3 — dots — to formula by Thomson [4]; 4 — thin solid line — Fabrikant formula [6]; 5 — dash-dotted line — the "bornov" approximation used in references [1] and [2].

To conditions in solar chromosphere and corona, in which electron temperature $T_e \lesssim 10^6$ °K, correspond the mean electron energies $E \lesssim 90$ eV. That is why we are in fact interested in the form of the dependence q (E) for $E < 200 - 300$ eV. As may be seen from Fig. 1, the "bornov" approximation used by V. M. Sobolev in [1] and by Shklovskiy in [2], begins to get nearer the experimental data precisely in that energy range. That is why Sobolev represented these data in his subsequent work [3] with the aid of Fabrikant's empirical formula [6], which gives underrated results for great values. A. B. Severnyy [4] applied for the effective ionization cross section the Thomson formula, representing well the experimental curve near the ionization threshold. However the maximum of this curve takes place earlier than that of the experimental curve.

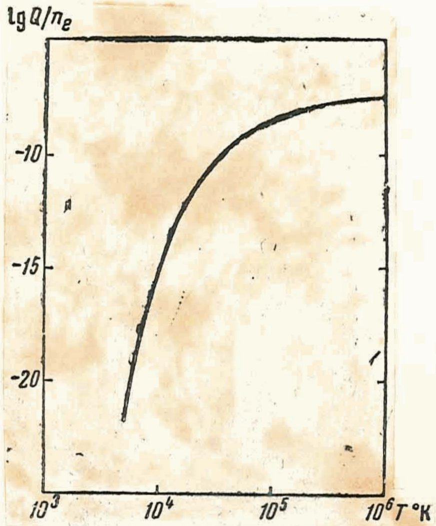

Fig. 2

A better approximation is is constituted by the following empirical formula obtained by us :

$$q_{1i}(E) = 3.14\cdot 10^{-16}\frac{E-\chi_1}{E^{1+\alpha}}, \qquad (2)$$

where $\alpha = 0.3$, and E is expressed in electron-volts.

Substituting it into formula (1) and effecting the corresponding transformations, we obtain for the probability of ionization from the ground state the following expression :

$$Q_{1i} = 3.14\cdot 10^{-16} n_e \sqrt{\frac{8kT_e}{\pi m_e}}\,\frac{x_1}{\chi_1^{\alpha}}\left\{x_1^{\alpha-1}\int\limits_{x_1}^{\infty}\frac{e^{-x}}{x^{\alpha-1}}\,dx - x_1^{\alpha}\int\limits_{x_1}^{\infty}\frac{e^{-x}}{x^{\alpha}}\,dx\right\}, \qquad (3)$$

where $x_1 = 11605\ \chi_1/T$.

It may be shown that similarly to the known logarithm integral representation in the form of finite sum, the following correlation is valid :

$$x_1^{\alpha}\int\limits_{x_1}^{\infty}\frac{e^{-x}}{x^{\alpha}}\,dx = e^{-x_1}\left\{1-\frac{\alpha}{x_1}+\frac{\alpha(\alpha+1)}{x_1^2}-\ldots\right.$$
$$\left.\ldots(-1)^n\frac{\alpha(\alpha+1)\ldots(\alpha+n)}{x_1^{n+1}}+R_n\right\}, \qquad (4)$$

where $|R_n| < \frac{(n+2)!}{x_1^{n+2}}$. provided $\alpha < 1$.

Then, applying to each of the integrals (3) formula (4) with two addends in the sum, we finally obtain

$$Q_{1i} \approx 2.27\cdot 10^{-6}\chi_1^{1-\alpha}\frac{n_e}{\sqrt{T_e}}\,\frac{e^{-x_1}}{x_1} = 1.41\cdot 10^{5}\frac{n_e}{\sqrt{T_e}}\,\frac{e^{-x_1}}{x_1} =$$
$$= 0.89\cdot 10^{-10}\sqrt{T_e}\,e^{-\chi_1/kT_e}. \qquad (5)$$

Inasmuch as this formula, as may be seen from the estimate of R_n, gives so much the greater error as the temperature is higher, we computed Q_{ik} for the three values $T_e = 10^4, 10^5, 10^6$ °K by numerical integration directly by formula (1) with the experimental values of q (E) from Fig. 1. The results of the numerical integration for the indicated temperatures gave respectively

$$Q_{1i} = 1.14 \cdot 10^{-15};\ 4.47 \cdot 10^{-9} \text{ and } 3.11 \cdot 10^{-8},$$

while according to formula (5)

$$Q_{1i} = 1.25 \cdot 10^{-15};\ 5.71 \cdot 10^{-9};\ 7.63 \cdot 10^{-8}.$$

Thus, this formula may be utilized to $T \lesssim 10\,000$°K with a precision to 20%.

We plotted in Fig. 2 the dependence of lg (Q_{1i}/n_e) on log T_e for q (E) corresponding to the experimental data (5).

If we take into account that in the final exprssion of formula (3.2) of reference [4] the sign — must stand instead of sign +, the corresponding approximate formula in our deisgnations shall have the form:

$$Q_{1i} = 5.469T^{-3/2}\left\{\frac{e^{-x_1}}{x_1} - [-\operatorname{li}(e^{-x_1})]\right\} \approx 2.2 \cdot 10^{-10} \sqrt{T_e}\, e^{-\chi_1/kT_e}, \qquad (6)$$

which is only 2.5 times more tham Q_{1i} according to formula (5). Let us note that as a consequence of the indicated error the probabilities of Q_{nf} in Table 3 of reference [4] are overrated, by for example for n = 1, 32 times.

On the other hand the probabilities of ionization from the ground level, computed by Sobolev [3] according to Fabrikant's formula, are about twice smaller than those computed by us.

For the determination of the total number of hydrogen atom ionizations it is necessary to account for the ionizations from excited levels, as this was shown in [7]. The ionization probability from the ground level according to formula (27) of that work is about twice as great as that obtained by us, on account of admitted inaccurate representation in it of the effective cross section near the very threshold of ionization.

Therefore, in order to determine the ionization probability of hydrogen from the ground level for temperatures lower than the 20 000 – 50 000°K range, formula (5) must be used, while for greater temperature values must be taken from the graph of Fig. 2.

In concluding we wish to express our gratitude to G. I. Olimpiyeva for conducting control calculations.

**** THE END ****

STATE ASTRONOMICAL INSTITUTE
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